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Natural Resource Stewardship and Science

Chemical Composition of Rivers in Alaska's Arctic Network, 2013-2014

Natural Resource Data Series NPS/ARCN/NRDS—2015/809

ON THIS PAGE
Photograph of Dr. Tom Trainor processing water samples collected from the main-stem of the Kobuk River, Kobuk Valley National Park, Alaska.
Photograph courtesy of the National Park Service.

ON THE COVER
Photograph of the Killik River flowing through the Brooks Range in Gates of the Arctic National Park.
Photograph courtesy of the National Park Service.

Chemical Composition of Rivers in Alaska's Arctic Network, 2013-2014

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June 2015

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Please cite this publication as:

O'Donnell, J. A., G. R. Aiken, T. P. Trainor, T. A. Douglas, and K. D. Butler. 2015. Chemical composition of rivers in Alaska's Arctic Network, 2013-2014. Natural Resource Data Series NPS/ARCN/NRDS—2015/809. National Park Service, Fort Collins, Colorado.

NPS 953/128986, June 2015

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Abstract

The chemical composition of rivers is an important characteristic that can have considerable influence on aquatic ecosystem function and response to landscape change. Here, we report findings from a two-year pilot study aimed at characterizing the chemical composition of rivers in National Park Service lands of the Arctic Inventory and Monitoring Network (ARCN). We collected water samples from 57 rivers during the summer-autumn flow period (June-September) during the 2013 and 2014 field seasons. An additional five rivers were re-sampled during winter flow in March 2014. Water samples were analyzed for dissolved organic matter (DOM) composition, nutrient concentrations, major cations and anions, and water stable isotopes. We observed considerable variation in ehemical composition across study sites within ARCN parks. For instance, mean dissolved organic carbon (DOC) concentration varied across ARCN parks, ranging from 2 to 8 mgC L^{-1}. DOM character also varied across parks, as indicated by measurements of specific ultraviolet absorbance ($SUVA_{254}$) and through chemical fractionation of DOM. Both nitrogen and phosphorus concentrations were consistently low in all samples, indicating oligotrophic conditions and low production rates. Base cation concentrations and water stable isotopes are useful indicators of watershed hydrogeology and the relative influence of groundwater across rivers. We observed high concentrations of dissolved iron in rivers of Kobuk Valley National Park. This elevated iron appears to be influenced by the amount and composition of DOM leaching from local pristine soils into the rivers. Overall, rivers in the ARCN parks appear to be unimpaired with respect to carbon, nutrients and trace metals. However, Arctic rivers may be vulnerable to climate-driven changes in the soil thermal regime, hydrology, and disturbance (permafrost thaw, erosion, wildfire), all of which can alter the chemical composition of surface water. Future monitoring of ARCN rivers should be designed to detect chemical and hydrologic properties across space and time, both as a means of assessing these vulnerabilities and for improving watershed management activities.

Acknowledgments

We thank Kathryn Motter for facilitating sample analysis at the Cooperative Chemical Analytical Laboratory at Oregon State University. We thank Dr. Amy Larsen, Dr. Jim Lawler, and Trey Simmons for their edits and comments on an earlier version of this report.

Introduction

Warming air temperatures are altering watershed hydrology and aquatic ecosystems in the Arctic, which can have a profound impact on the chemical composition of streams and rivers (Frey and McClelland 2009). Riverine carbon and nutrient dynamics are sensitive to both direct and indirect effects of warming on changing seasonality. The most dramatic changes have been reported for the timing of spring snowmelt and river-ice break-up, and for landscape disturbance regimes (*e.g.* permafrost thaw and wildfire; Betts *et al*. 2009; O'Donnell *et al*. 2012, 2014). While most rivers in the Arctic are unimpaired, warming has already caused changes in river chemical composition. For instance, the flux of dissolved organic carbon (DOC) has declined in recent decades in the Yukon River basin, presumably in response to permafrost thaw and increasing groundwater discharge to streams (Striegl *et al*. 2005, Walvoord & Striegl, 2007). However, considerable uncertainty exists with respect to the response of riverine chemistry and solute export under projected warming and disturbance scenarios.

In general, the composition of river water is a reflection of physical, chemical, and biological processes occurring within the watershed that govern the concentration of different solutes. These processes are constantly interacting, and they vary across space and time. One important control on stream chemistry is the origin of different source waters that generate flow (O'Donnell *et al*. 2010). For instance, stream DOC concentration typically reaches an annual maximum during spring snowmelt (Finlay *et al*. 2006), when flow is dominated by surface runoff and shallow sub-surface flow through organic-rich soils. DOC concentrations are typically lowest during winter flow, when flow originates primarily from deep groundwater flowpaths (O'Donnell *et al*. 2012). Conversely, mineral solute concentrations (*e.g.* calcium, magnesium) are often elevated when groundwater discharge is high, and low when flow is derived from surface runoff (*e.g.* Maclean *et al*. 1999). In-stream processes can also play an important role in determining river chemistry through the production, uptake, and transformation of different solutes (Cole *et al*. 2007; Battin *et al*. 2009).

Stream biogeochemistry, encompassing the cycling of organic matter, nutrients, major ions, and trace metals, can have significant implications for aquatic biota. Dissolved organic matter (DOM) can influence stream pH, redox conditions, the transport and reactivity of trace metals (*e.g.* mercury, copper), and nutrient availability. The relative importance of DOM in aquatic systems varies with its chemical composition, which is expected to change under projected warming and permafrost thaw (O'Donnell *et al*., 2012, 2014). In most Arctic streams, phosphorous (P) is the primary limiting nutrient governing primary production (Peterson *et al*. 1985). For example, long-term P fertilization of the Kuparuk River near the Toolik Field Station in northern Alaska has altered stream ecosystem function, leading to enhanced moss and algal productivity, invertebrate production, and fish production (Slavik *et al*. 2004). Warming and disturbance will likely increase both nitrogen (N) and P inputs to streams from soils (*e.g.* Bowden *et al*. 2008), driving bottom-up effects on food web dynamics.

The aim of the present study is to provide baseline chemical data for streams and rivers in the Arctic Inventory and Monitoring Network (ARCN). ARCN is comprised of five NPS park units, covering more than 78,000 km^2 in northern Alaska with over 40,000 km of streams and rivers. The area is extremely remote and pristine with almost no road access and minimal anthropogenic impacts. The intent of the program is to assess and track the overall condition of park resources through the monitoring of 19 vital signs (Lawler *et al*. 2009). Herein, we present results from a pilot study conducted in 2013 and 2014 as a component of the Stream Communities and Ecosystems Vital Sign. Data from this study will be used to guide protocol development for long-term monitoring and for selection of intensive and extensive study sites. Overall, our aim is to improve management practices in watersheds of ARCN park units through targeted data collection and interpretation.

Methods

Overview

We sampled 57 streams and rivers across the five National Park Service units of the Arctic Inventory and Monitoring Network (ARCN), including Bering Land Bridge National Preserve (BELA), Cape Krusenstern National Monument (CAKR), Gates of the Arctic National Park (GAAR), Kobuk Valley National Park (KOVA), and Noatak National Preserve (NOAT). Streams ranged in size from small headwater streams (*e.g.* Fairhaven Ditch, Kavet Creek) to large rivers (Noatak River, Kobuk River). We collected samples from all sites during summer-autumn flow conditions (mid-June through September: BELA samples were collected between June 21-23, 2013; KOVA samples were collected between August 20-24, 2013; and NOAT samples were collected between June 27-28 and September 15-16, 2013. In March 2014, additional samples were collected under winter flow condition from five sites (Kelly, Killuk, Kobuk, Noatak, and Nugnugaluktuk Rivers).

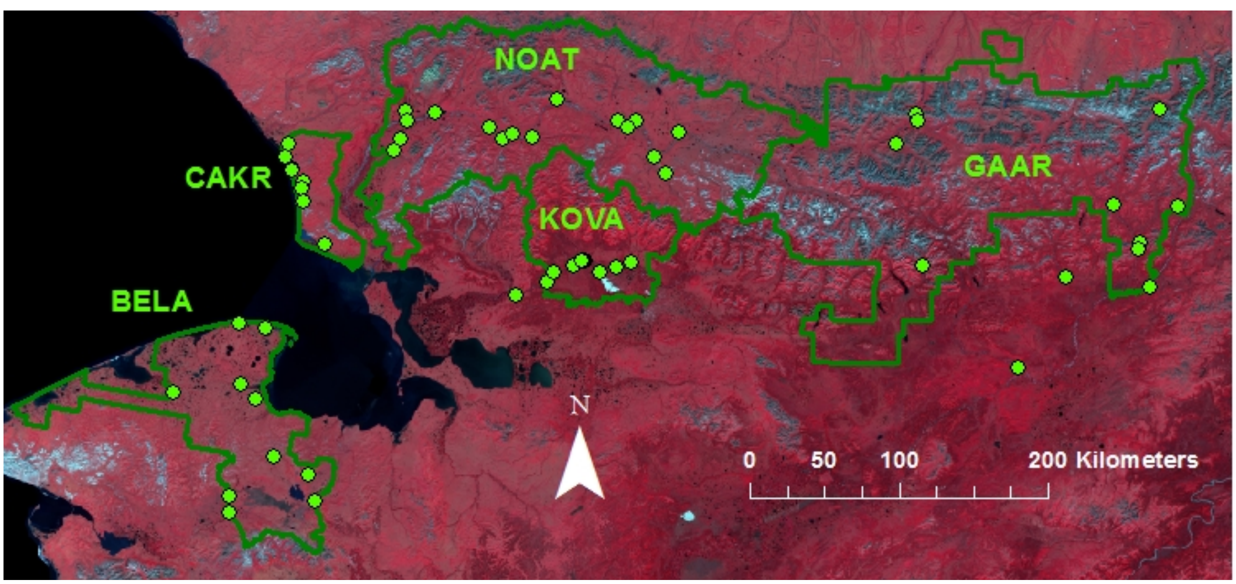

Figure 1. All study sites (n = 57 streams or rivers) in National Park Service units of the Arctic Inventory and Monitoring Network (ARCN), including Bering Land Bridge National Preserve (BELA), Cape Krusenstern National Monument (CAKR), Gates of the Arctic National Park (GAAR), Kobuk Valley National Park (KOVA), and Noatak National Preserve (NOAT).

At each study site we collected water samples to analyze dissolved organic matter (DOM) composition, nutrient concentrations (nitrogen (N) and phosphorous (P) species), major cations and anions, and water stable isotopes (^{18}O and ^{2}H). At a sub-set of sites (n = 12 sites within KOVA), we also measured trace metal concentrations and iron (Fe) speciation. We also conducted in situ measurements of water temperature, conductivity, and pH at each study site.

Table 1. Study sites from 2013-2014 pilot studies in the Arctic Network.

Site Name	Sampling Date(s)	Lat (°N)	Long (°W)
Bering Land Bridge National Preserve			
Espenberg River	6/22/13	66.55844	-164.01575
Fairhaven Ditch	6/23/13	65.72146	-163.08076
Goodhope River	6/23/13	65.79816	-163.61961
Killuk River	6/22/2013, 3/25/2014	66.56224	-164.41152
Kugruk River	6/21/13	65.56703	-162.92764
Kuzitrin River	6/21/13	65.42459	-164.13533
Noxapaga River	6/21/13	65.52092	-164.16145
Nugnugaluktuk River	6/22/2013, 3/25/2014	66.19823	-164.24932
Pish River	6/23/13	66.12493	-164.00930
Serpentine River	6/23/13	66.08588	-165.21670
Cape Krusenstern National Monument			
Agagrak River	7/15/14	67.52573	-163.97139
Jade Creek	7/15/14	67.42507	-163.78374
Kilikmak Creek	7/15/14	67.34982	-163.73915
New Heart Creek	7/15/14	67.60598	-164.10596
Omikviorok River	7/15/14	67.68031	-164.10309
Rabbit Creek	7/15/14	67.46954	-163.77065
Situkuyok River	7/16/14	67.11598	-163.30933
Umagatsiak Creek	7/15/14	67.54105	-163.99144
Gates of the Arctic National Park			
Alatna River	8/6/14	66.61375	-152.62088
April Creek	8/6/14	67.97904	-154.48900
Easter Creek	8/6/14	68.12324	-154.12885
Glacier River	8/5/14	67.34798	-150.67937
Hammond River	8/7/14	67.55306	-150.05061
Itkillik River	8/8/14	68.14980	-150.24098
John River	8/6/14	67.15272	-151.83421
Killik River	8/6/14	68.15578	-154.15880
Kobuk River Headwaters	8/7/14	67.23957	-154.06416
Middle Fork Koyukuk River	8/7/14	67.07641	-150.54996
North Fork Koyukuk River	8/5/14	67.30995	-150.70750
Tinayguk River	8/5/14	67.58109	-151.06390
Kobuk Valley National Park			

Table 1. Study sites from 2013-2014 pilot studies in the Arctic Network (*continued*).

Site Name	Sampling Date(s)	Lat (°N)	Long (°W)
Ahnewetut Creek	8/20/13	67.16714	-158.78334
Akillik River	8/20/13	67.20069	-158.57192
Elaroniluk Creek	8/22/13	67.04250	-159.83401
Kaliguricheark River	8/21/13	67.19281	-159.27368
Kallarichuk River	8/22/13	67.10559	-159.74061
Kavet Creek	8/20/13	67.12818	-159.03391
Kobuk River at Kavet Creek	8/20/13	67.12997	-159.03638
Kobuk River near Kiana	8/23/2013, 3/24/2014	66.94345	-160.29672
Nigeruk Creek	8/21/13	67.18271	-159.30174
Salmon River	8/21/13	67.15444	-159.45956
Tutusuk River	8/21/13	67.19038	-159.34482
Noatak National Preserve			
Aklumayuak River	6/28/13	67.90478	-160.26924
Anisak River	9/16/13	68.05419	-158.94021
Aniuk River	9/15/13	68.00692	-157.94259
Cutler River	9/15/13	67.84507	-158.31574
Eli River	6/27/13	67.73255	-162.42036
Imelyak River	9/15/13	67.75084	-158.11521
Kaluktavik River	6/28/13	67.94525	-160.95707
Kelly River	6/27/2013, 3/24/2014	67.98631	-162.32442
Kugururok River	6/27/13	67.99566	-161.86693
Makpik River	9/16/13	68.06024	-158.64146
Nakolik River	6/28/13	67.87414	-160.75191
Nanielik Creek	9/16/13	68.01035	-158.77109
Nimiuktuk River	6/28/13	68.14954	-159.94803
Noatak River	6/27/2013, 3/24/2014	67.92345	-162.29388
Sisiak River	6/28/13	67.91108	-160.59192
Uvgoon Creek	6/27/13	67.80735	-162.34694

Site descriptions, measurements, and sample collection

Water samples were collected 25 cm below the surface in a well-mixed location with at least three river widths of distance below any confluences. All samples were filtered *in situ* using a 0.45-µm high-capacity capsule filter connected to a Geopump Series II Peristaltic Pump (Geotech Environmental Equipment, Inc., Denver, CO). Prior to collecting a water sample we pre-rinsed each capsule filter by running approximately 1.5 L of sample water through each filter. Samples collected for DOM fractionation were stored in 1-L amber glass bottles, whereas samples collected for other DOM measurements (DOC concentration, optical properties, etc.) were stored in 125-mL amber glass bottles. For cations, anions, and nutrients, filtered water samples were stored in 500-mL polycarbonate bottles. Samples collected for Fe speciation were stored in 125-mL amber polycarbonate bottles and acidified with 6N HCl in the field, whereas trace metal samples were acidified with nitric acid in the field. Unfiltered water samples were collected for analysis of total N and P.

Dissolved organic matter composition

DOM was characterized for dissolved organic carbon (DOC) concentration, optical properties (ultraviolet-visible (UV) absorbance, fluorescence), and major chemical fractions (XAD-8/XAD4 fractionation) at the U.S. Geological Survey organic carbon laboratory in Boulder, CO. DOC concentrations were determined using an O.I. Analytical Model 700 TOC analyzer via the platinum catalyzed persulfate wet oxidation method (Aiken et al. 1992). Stream water samples were chromatographically separated into different fractions: hydrophobic acids (HPOA), hydrophobic neutrals (HPON), hydrophilic organic matter (HPI), and transphilic acids (TPIA) using Amberlite XAD-8 and XAD-4 resins (Aiken et al. 1992). The resins preferentially sorb different classes of organic acids based on aqueous solubility of the solute, chemical composition of the resin, resin surface area, and resin pore size. The amount of organic matter within each fraction, expressed as a percentage of the total DOC concentration, was calculated using the DOC concentration and the sample mass of each fraction. The standard deviation for the mass percentages of each fraction was ± 2%.

We used several approaches for analyzing and reporting the optical properties of chromophoric DOM (CDOM). Decadal UV-Visible absorbance (A) was measured on bulk DOC samples and HPOA fractions before lyophilization at room temperature using a quartz cell with a path length of 1 cm on an Agilent Model 8453 photo-diode array spectrophotometer. The Naperian absorption coefficient at 254 nm (α_{254}) has been shown to serve as a proxy for both DOC concentration and Δ^{14}C-DOC in the YRB system (Spencer et al. 2009; O'Donnell et al. 2012, 2014; Aiken et al. 2014). We determined specific UV absorbance ($SUVA_{254}$) on HPOA isolates by dividing the decadal absorption coefficient at $\lambda = 254$ nm (A_{254}) by DOC concentration. $SUVA_{254}$, which is typically used as an index of DOC aromaticity (Weishaar *et al*., 2003), is reported in units of L mgC m^{-1}. Weishaar *et al*. (2003) also showed that UV absorbance values can be influenced by the presence of Fe. For bulk DOC samples containing Fe, we applied correction factors based on experimental work by Poulin *et al*. (2014), who observed a significant positive correlation between A_{254} and the concentration of Fe^{3+}, reflected by the equation $A_{254\text{-}corrected} = A_{254\text{-}measured} - 0.0687*[Fe^{3+}]$ ($R^2 = 0.98$; $P < 0.0001$; n = 22). Using this relationship, we corrected A_{254} for samples where we measured total Fe concentration.

Nutrients, cations, and anions

Nutrient, cation, and anion analyses were performed at the Cooperative Chemical Analytical Laboratory (CCAL) at Oregon State University in Corvallis, OR (website: *ccal.oregonstate.edu*). Unfiltered water samples were analyzed for total nitrogen (TN) and total phosphorous (TP) by persulfate digestion (Ameel *et al*. 1993) followed by colorimetric analysis on a Technicon Auto-Analyzer II (Seal Analytical, Mequon, Wisconsin). Total dissolved nitrogen (TDN) and phosphorous (TDP) were also determined using the persulfate digestion method on filtered water samples. Nitrate

(NO_3^-) + nitrite (NO_2^-) was determined following the cadmium reduction method, and ammonia (NH_3) was determined following the phenate method. Orthophosphate, or soluble reactive phosphorous (SRP), was determined using the ascorbic acid method. Calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+) were analyzed using flame atomic absorbance spectroscopy on a Shimadzu AA-7000. Bromide (Br^-), chloride (Cl^-), and sulfate (SO_4^{2-}) were analyzed on a Dionex 1500 ion chromatography system.

Water isotopes

Stable isotopes of oxygen and hydrogen were measured using Wavelength-Scanned Cavity Ringdown Spectroscopy on a Picarro L2120i (Sunnyvale, California) at the U.S. Army Cold Regions Research and Engineering Laboratory's (CRREL) Alaska Geochemistry Laboratory on Fort Wainwright, Alaska. Each standard and sample was injected into the analyzer for seven separate analyses. Results from the first four injections were not used to calculate the stable isotope values to ensure there was no internal system memory. The mean value from the final three sample injections was used to calculate the mean and standard deviation value for each sample. Values are reported in standard per mil notation. Repeated analyses of five internal laboratory standards representing a range of values greater than the samples analyzed and analyses of SMOW, GISP, and SLAP standards (International Atomic Energy Agency) were used to calibrate the analytical results. Based on thousands of these standards analyses and of sample duplicate analyses we estimate the precision is <0.25‰ for $\delta^{18}O$ and <0.75‰ for δ^2H.

Trace metals and Fe speciation

Samples collected from the Kobuk River basin were analyzed for trace metal concentration and Fe speciation at the University of Alaska Fairbanks Department of Chemistry in Fairbanks, AK. Metal concentrations were measured using an Agilent 7500ce (Agilent Technologies, Santa Clara, CA) inductively coupled plasma-mass spectrometer (ICP-MS) following the general procedure outlined in Creed *et al*. (1994). To remove the polyatomic interferences during analysis the ICP-MS was operated in collision/reaction cell (CRC) mode using either He or H_2 gases following established protocols (Wilbur and Soffey, 2004). Six calibration standards with 1-100 ppb of each analyte were made by diluting 1,000 µg/ml single element standard solutions provided by ULTRA Scientific (Kingstown, RI). 2% ultrapure HCl was used as a blank. Calibration was performed at the beginning of each analytical run. The resulting calibration curves had R^2 values of 0.998 or better. Both a check standard and blank were run repeatedly throughout the course of the analysis (after every 10 samples) and all samples were analyzed in triplicate to quantify analytical uncertainty for each sample. (-) concentration was below the detection limit of the ICP-MS.

The Fe(II)/FeTot analysis we carried out following the ferrozine procedure outlined by Bangthanh *et al*. (1999). Absorbance values were measured using a Lambda 900 UV/VIS/NIR spectrometer. Calibration was performed using seven standards (ferrous chloride dissolved in 18.1 MΩ ultrapure water), resulting curve had an R^2 value of 0.9999.

Results

DOC concentration in ARCN rivers varied by park unit (Figure 2a). On average, DOC concentrations were highest in rivers of BELA (mean ± standard error = 7.8 ± 1.3 mg L^{-1}), and lowest in rivers of GAAR (2.4 ± 0.3 mg L^{-1}). Variation in DOC concentration across rivers and park units likely reflects differences in source water (wetlands vs. groundwater vs. glacier melt) contribution to stream flow (O'Donnell *et al*. 2010). $SUVA_{254}$ values also varied by park unit (Figure 2b). Rivers in BELA were highest, averaging 3.4 ± 0.2 L mgC m^{-1}. Rivers in GAAR were the lowest, averaging 2.1 ± 0.1 L mgC m^{-1}. $SUVA_{254}$ values serve as an index of DOM aromaticity (Weishaar *et al*. 2003), with high values indicating a higher proportion of aromatic compounds or structures, and low values indicating a higher proportion of aliphatic compounds. The high $SUVA_{254}$ values in BELA likely reflect inputs from near-stream, organic-rich soils, whereas the low values in GAAR reflect inputs form regional groundwater sources.

HPOA was the dominant chemical fraction of DOM in rivers across four ARCN park units (Figure 3; we did not collect large-volume samples for chemical fractionation from KOVA, due to logistical constraints of the float trip). However, the mean HPOA percentage varied across parks. For instance, NOAT rivers had the highest percentage of HPOA, averaging 51 ± 5%, whereas GAAR and CAKR had the lowest percentage of HPOA, averaging 37 ± 7 and 39 ± 5 %, respectively. TPIA averaged between 20 and 22% across four ARCN park units. HPI was quite variable across ARCN park units, ranging from 16% in NOAT rivers to 25% in GAAR rivers. The HPOA fraction is commonly associated with humic and fulvic acids, and are often derived from organic-rich soils in Alaskan watersheds (Wickland *et al*. 2007; O'Donnell *et al*. 2010). The HPI fraction is comprised of low molecular-weight compounds, which can be quickly mineralized by aquatic and soil microbes (Qualls & Haines 1992).

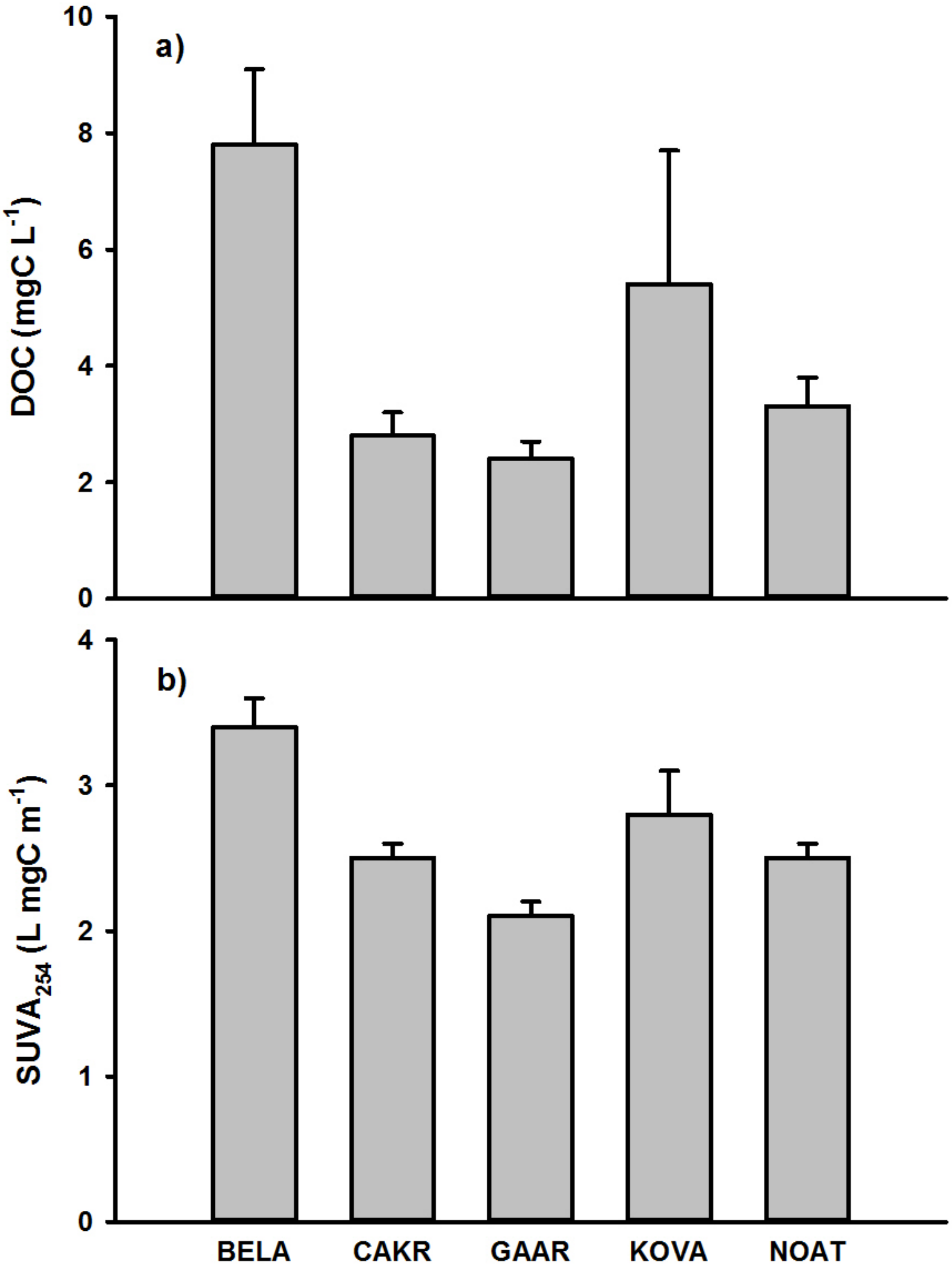

Figure 2. Mean DOC concentration (a) and SUVA254 values (b) for rivers across the five ARCN park units. Error bars represent one standard error.

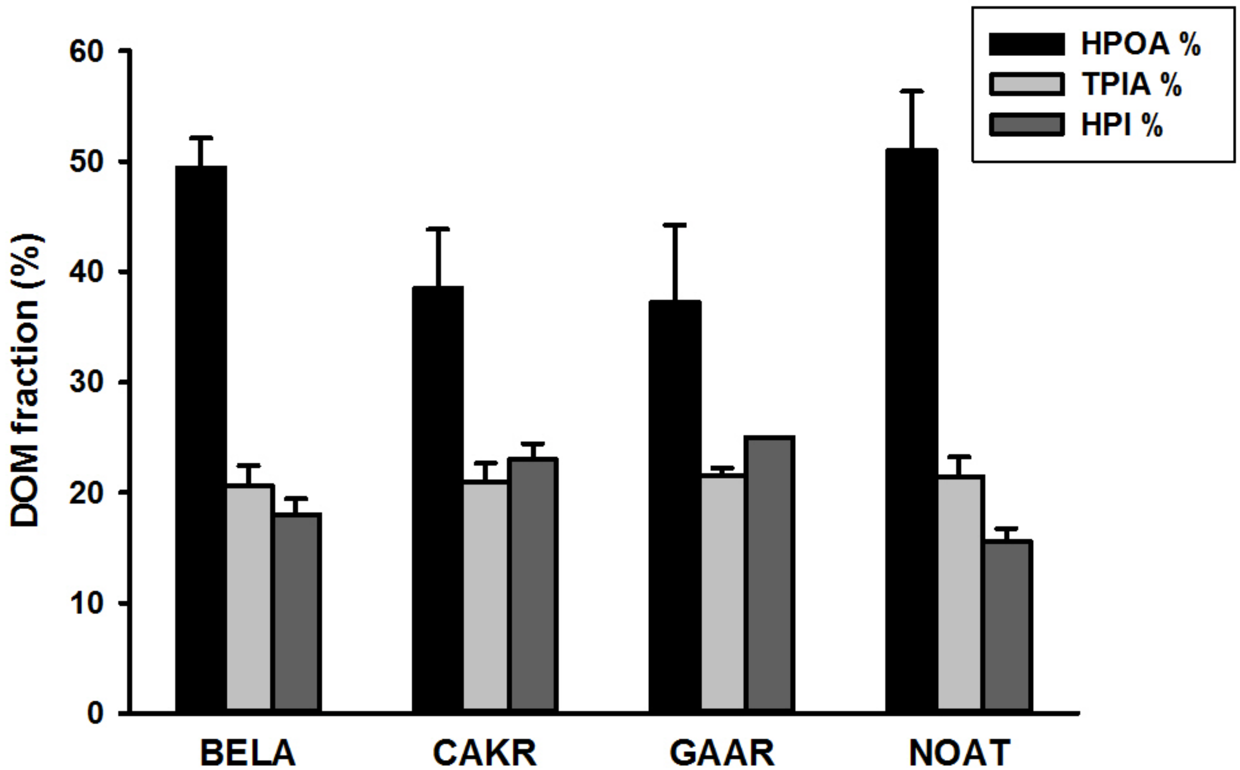

Figure 3. Major chemical fractions of dissolved organic matter (DOM) across four ARCN park units. HPOA (%) = hydrophobic organic acid; TPIA (%) = transphilic organic acid; HPI (%) = hydrophilic compounds.

Nitrogen species also varied by ARCN park unit (Figure 4). TN concentration was only measured in rivers of CAKR and GAAR, averaging 0.15 ± 0.1 mgN L^{-1}, collectively. TDN concentration was highly variable across ARCN park units, with the highest values observed in BELA (0.32 ± 0.06 mgN L^{-1}) and lowest in NOAT (0.13 ± 0.01 mgN L^{-1}). NO_3^- was the dominant form of inorganic N across most rivers, with NH_3 values near or below detection limit in many cases. Dissolved organic N (DON) concentrations were substantially higher than dissolved inorganic N (DIN) concentrations across park units. In general nitrogen concentrations in these rivers are low, reflecting unimpaired, oligotrophic conditions. PO_4^{-3} concentration was at or below detection limit for almost all rivers (data not shown here). This observation supports prior studies that have reported a strong P limitation of primary production in remote rivers of Alaska (Slavik *et al*. 2004).

Base cation concentrations varied, both in amount and composition across the ARCN park units (Figure 5). The sum of all base cations was generally highest in rivers of GAAR and lowest in BELA and KOVA. The high concentrations in GAAR rivers is likely a product of bedrock mineral weathering, followed by transport and discharge to stream flow via groundwater. Longer or deeper flowpaths are typically associated with an increased mineral weathering signature (i.e. higher cation concentrations) compare to streams with shallow flowpaths. The presence or absence of permafrost along a stream's reach could greatly affect the paths and seasonality of stream flows. In BELA, the lower cation concentrations may reflect the dominance of organic soils and shallow subsurface flow paths on the Seward Peninsula. In KOVA, the low cation concentrations are likely a reflection of

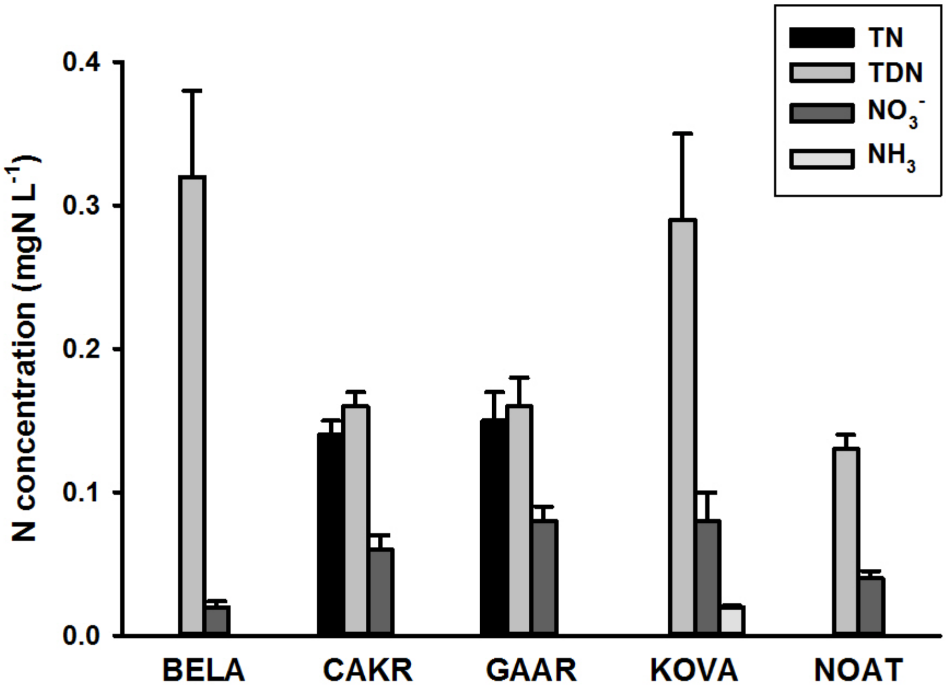

Figure 4. Total nitrogen (TN), total dissolved nitrogen (TDN), nitrate (NO_3^-), and unionized ammonia (NH_3) concentrations across five ARCN park units.

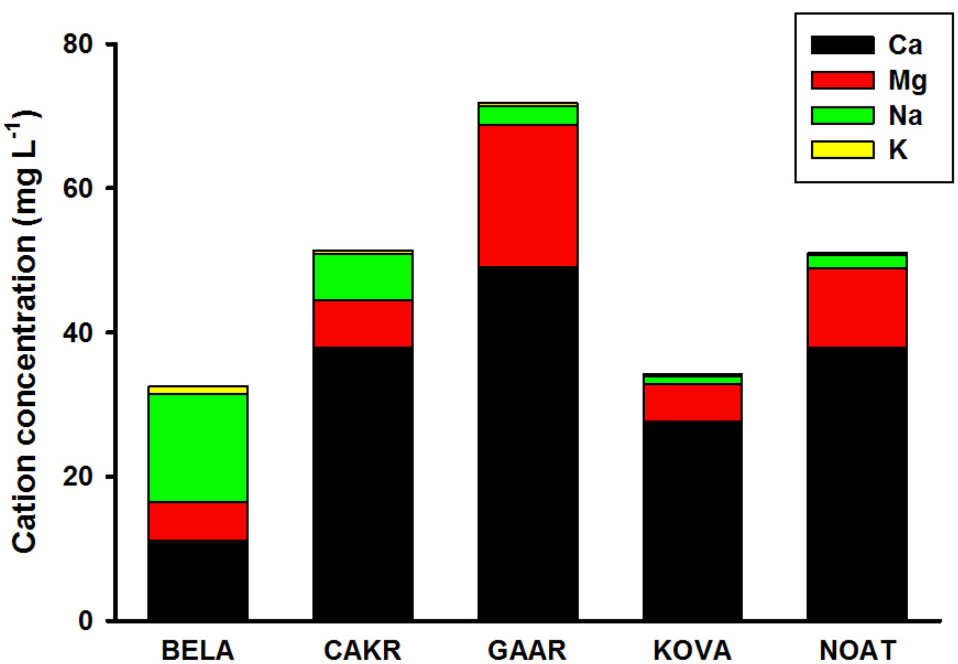

Figure 5. Mean base cation concentration across five ARCN park units. Ca = calcium; Mg = magnesium; Na = sodium; K= potassium.

both the depth of subsurface flows and lower weathering rates. Of the four base cations, Ca2+ dominated in all ARCN park units except BELA. In BELA, Na+ concentrations exceeded the other three cations, perhaps reflecting the influence of coastal processes on river chemistry on the Seward Peninsula. Alternately, the relatively high Na^+ concentrations may reflect different lithology of the region.

We observed a significant and positive correlation between ^{18}O and ^{2}H isotopes across three ARCN Park units (Figure 6). This was expected due to the lack of evaporate basins or other potential hydrologic fractionation sources in the watersheds. For rivers in BELA, ^{2}H values are enriched relative to rivers in KOVA and NOAT, ranging from -135 to -110 ‰. Water stable isotope patterns are influence by many factors, including latitude, temperature, proximity to coastal storms, and the relative influence of snow vs. rain vs. groundwater.

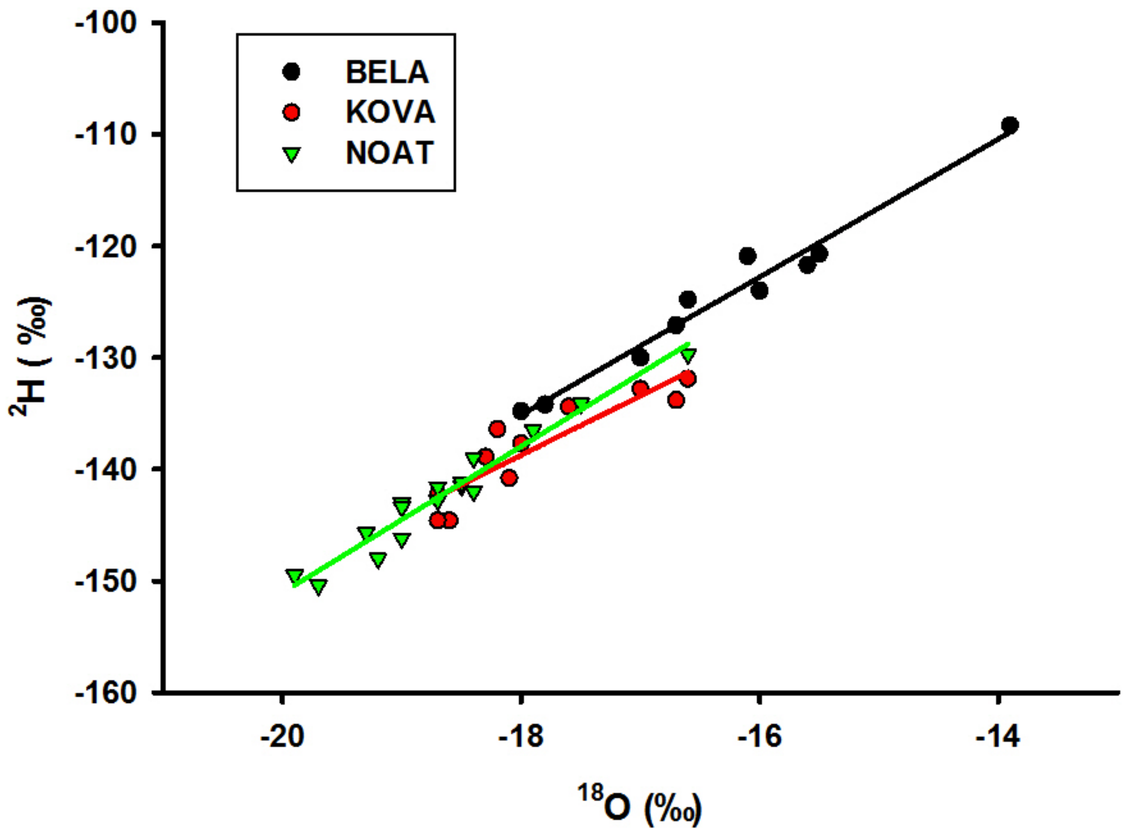

Figure 6. Linear regression between ^{18}O and ^{2}H (deuterium) across three ARCN park units. Linear regression statistics by ARCN park unit: BELA: $^{2}H = 6.17^{18}O - 24$, $R^2 = 0.97$, $P < 0.0001$. KOVA: $^{2}H = 5.3^{18}O - 43$, $R^2 = 0.82$, $P = 0.0001$. NOAT: $^{2}H = 6.5^{18}O - 20$, $R^2 = 0.95$, $P < 0.0001$. 8240

Total Fe concentrations were higher than other trace metal concentrations in rivers of KOVA (Figure 7), ranging from 200 to nearly 4000 μg L^{-1}. We observed the highest values for both Al and Fe in

Nigeruk Creek, measured at 84.3 and 3930.9 μg L^{-1}, respectively. Nigeruk Creek is a blackwater stream, characterized by high DOC concentrations and a high proportion of reactive, aromatic DOM (i.e. high $SUVA_{254}$ values).

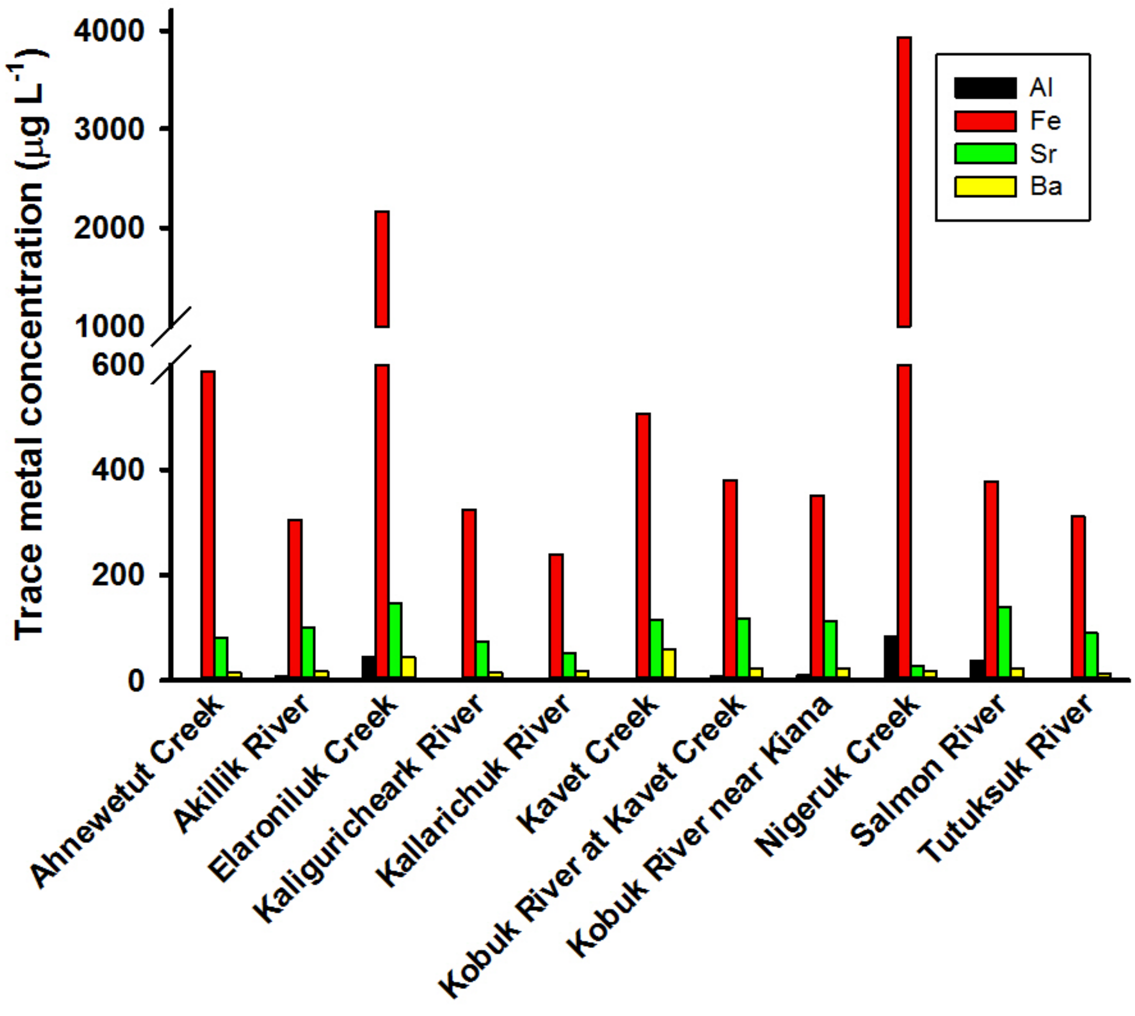

Figure 7. Select trace metal concentrations in KOVA rivers. Al = aluminum; Fe = iron; Sr = strontium; Ba = barium.

The DOC concentration in rivers of KOVA is positively correlated with total Fe, reduced Fe, and oxidized forms of Fe (Figure 8). We also observed a positive non-linear relationship between the proportion of reduced iron ($Fe(II)/Fe_{tot}$) and $SUVA_{254}$ (Figure 9), an index of DOM aromaticity. These observed relationships between Fe, DOC concentration, and DOM composition are likely the product of different hydrogeological and geochemical processes. First, in rivers where DOC and Fe concentrations are both high, we hypothesize that this is driven by source water inputs from near-stream wetlands and saturated riparian zones. These are critical zones within watersheds where DOC and Fe can both accumulate in soils and also function as a source for aquatic systems through hydrologic flushing. It is also possible that aromatic forms of DOM may be binding with reduced Fe, driving the positive correlation observed in Figure 9.

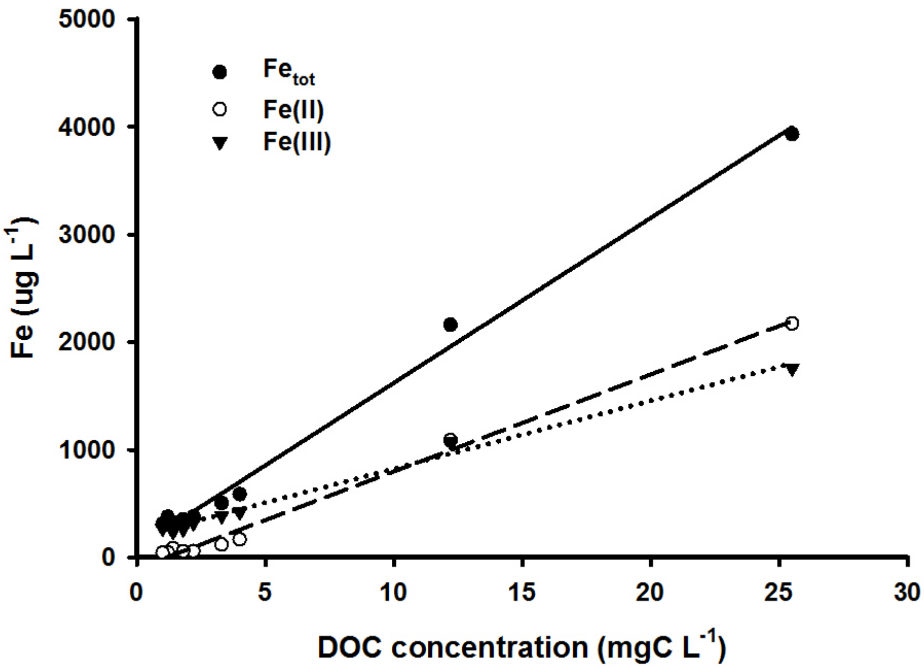

Figure 8. Relationship between different Fe species and DOC concentration for rivers in KOVA. Fe_{tot} = total Fe concentration; Fe(II) = reduced iron concentration, Fe(III) = oxidized iron concentration. Linear regression statistic: Fe_{tot}: y = 153x +90, R^2 = 0.99, P < 0.001. Fe(II): y = 90x -103, R^2 = 0.99, P < 0.0001. Fe(III): y = 63x +192, R^2 = 0.99, P < 0.001.

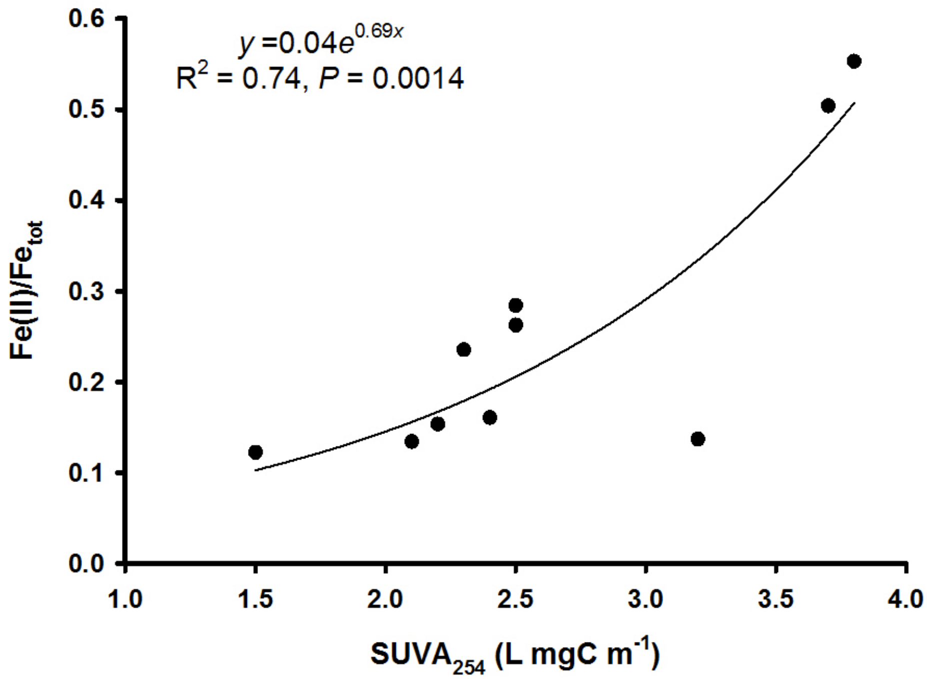

Figure 9. Exponential relationship between the proportion of reduced iron, or Fe(II), to total iron, or Fe_{tot}, and $SUVA_{254}$ values in rivers of KOVA.

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Appendix: Study Site Descriptions

Bering Land Bridge National Preserve

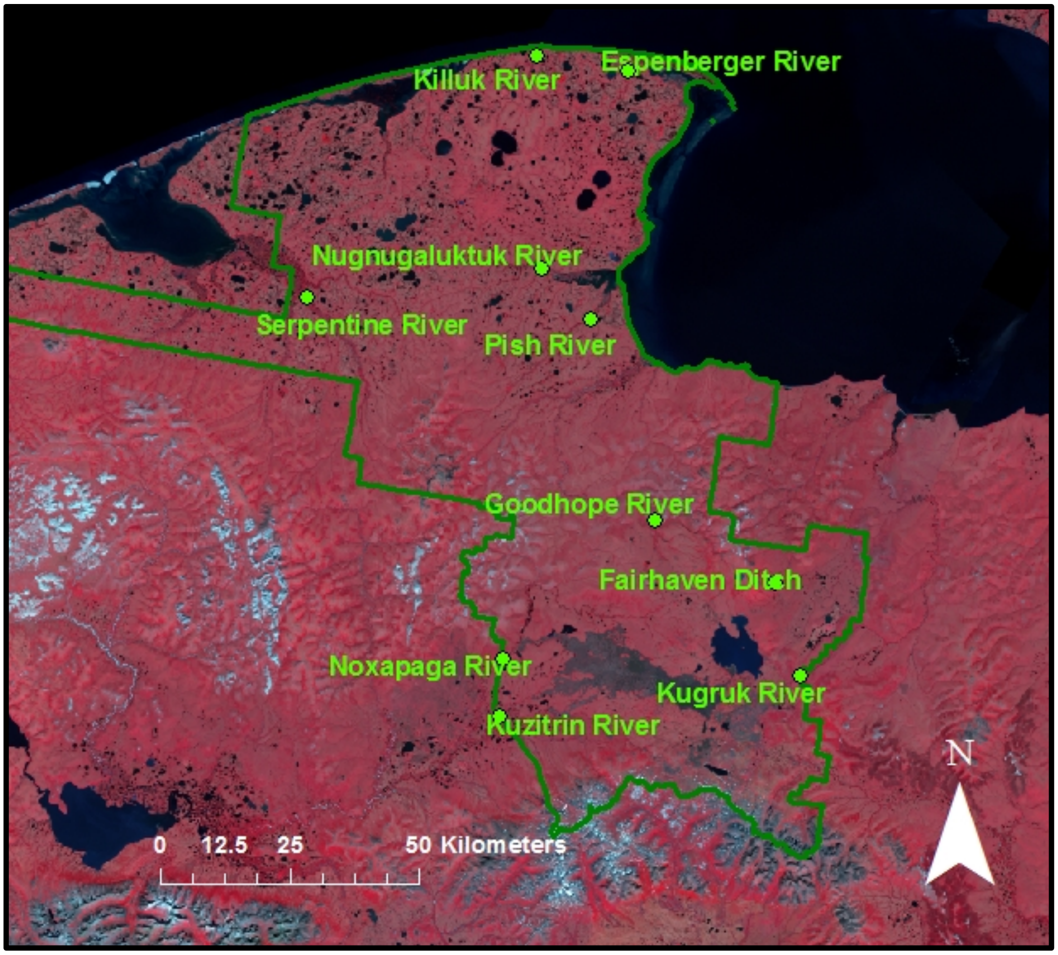

Figure A1. Map of study sites sampled in June 2013 in Bering Land Bridge National Preserve.

Espenberg River

The Espenberg River is a high-order tundra river flowing relatively straight and channelized through coastal plain. At our study reach, surface water was colored, indicating carbon-rich water. The river substrate was organic-rich, mucky silt. Riverbanks in this reach were steep and incised. In the riparian zone, vegetation transitioned from grazing lawns to short shrubs to tall shrubs with increasing distance from riverbank.

Figure A-2. The Espenberg River study site, sampled on June 22, 2013.

Fairhaven Ditch

Fairhaven Ditch is a headwater stream characterized by riffle-run-pool geomorphology. At our study site, surface water was dark in color, indicating presence of high DOC concentrations and aromatic DOM. River substrate was silty with many recognizable terrestrial plan parts. Flow was generally low, but velocity was spatially variable between riffle-pool reaches. Riparian vegetation was dominated by *Salix* and *Betula* spp. Runs were totally shaded by the riparian canopy, while pools are ~50% shaded.

Figure A-3. Fairhaven Ditch study site, sampled on June 23, 2013.

Goodhope River at Cottonwood

The Goodhope River at Cottonwood is a low-order stream draining a rocky upland watershed. At our study reach, the river substrate was rocky, with many smooth flat rocks (5-35 cm in length). A dense willow canopy dominated riparian vegetation. There was bright green moss (unknown species) colonizing along sand/silt bar. We observed low flow conditions during sampling. Caddis flies and stoneflies were observed under the river substrate.

Figure A-4. Goodhope River at Cottonwood study site, sampled on June 23, 2013.

Killuk River

The Killuk River drains a large watershed that spans a large portion of the northern coastal plain of the Seward Peninsula, winding through a basin dominated by volcanic sediments mixed with alluvial and aeolian silt deposits. We observed a cut bank at the study site, which exposed thick organic-rich silt deposits. River substrate was composed of finely pulverized volcanic material and small gravel, and geomorphic processes appear to be quite active. Vegetation along riverbanks dominated by *Salix* spp. Flow appears to be on the descending limb of the hydrograph following snowmelt, with some riparian willows partially below water table.

Figure A-5. Killuk River study site, sampled on June 22, 2013.

Kugruk River

This section of Kugruk River is high-gradient, high flow, with considerable rapids. Our sampling location was situated in a steep canyon with steep exposed rock faces. Many of the black rocks are colonized by orange lichen. River substrate was composed of large rocks and boulders with frequent algal biofilm and aquatic mosses.

Figure A-6. Aerial view of the Kugruk River, sampled on June 21, 2013.

Kuzitrin River

This reach of Kuzitrin River is low gradient and winding with many oxbox lakes within the floodplain. River sediments at our study reach were a mixture of fine (< 1 mm) to small gravel, with aquatic mosses covering < 5 % of sediment surface. We observed a small (~20 cm) juvenile whitefish at the site rising to river surface to feed on mosquitos.

Figure A-7. Picture of the Kuzitrin River, sampled on June 21, 2013.

Noxapaga River

The Noxapaga is a meandering mid-order river with large gravel and cobble substrate. The geomorphology of our study site was characterized by alternating shallow riffles, deep pools and channels, with numerous side channels. Stream flow appeared to be on the descending limb of the hydrograph following spring snowmelt. In riffles, we observed abundant caddis fly, mayfly, and black fly larvae.

Figure A-8. Noxapaga River study site sampled on June 21, 2013.

Nugnugaluktuk River

The Nugnugaluktuk River is a large, high-order tundra river, very similar in physiography to Espenberg River. We sampled the river near the mouth where it enters Kotzebue Sound. The river stage is approximately 75 cm below recent high-water mark. Also, it seems possible that changing tides of Kotzebue Sound may influence river stage. The channel was relatively deep and with incised riverbanks. Surface water was dark in color, indicating high organic carbon concentrations.

Figure A-9. The Nugnugaluktuk River study site, sampled on June 23, 2013.

Pish River

The Pish River is a tundra stream, but considerably smaller than the Espenberg and Nugnugaluktuk Rivers. The watershed is wide and shallow, typical of other basins along the coastal plain on the northern Seward Peninsula. River substrate at our study site was dominated by a mixture of fine and coarse sands and small sub-angular gravel. We observed frequent exposed and eroding silt terraces along riverbanks. River flow was low, with stage height two to three meters below the top of the bank. Surface water was colored, indicating high organic carbon concentrations.

Figure A-10. Pish River study site, sampled on 6/23/2013.

Serpentine River

As the name describes, the Serpentine River is a winding river draining vast peatlands with numerous oxbow lakes within basin. River substrate at our study site was a mixture of fine sand, silt, and small gravel. Riparian shrubs dominated by short and tall alder. During our visit, flow was low under summer baseflow conditions, with river stage approximately two meters below the recent high-water mark. A fraction river flow in the Serpentine is likely generated by geothermal groundwater sources, given the presence of Serpentine Hot Springs within the basin.

Figure A-11. Serpentine River study site, sampled on June 23, 2013.

Cape Krustenstern National Monument

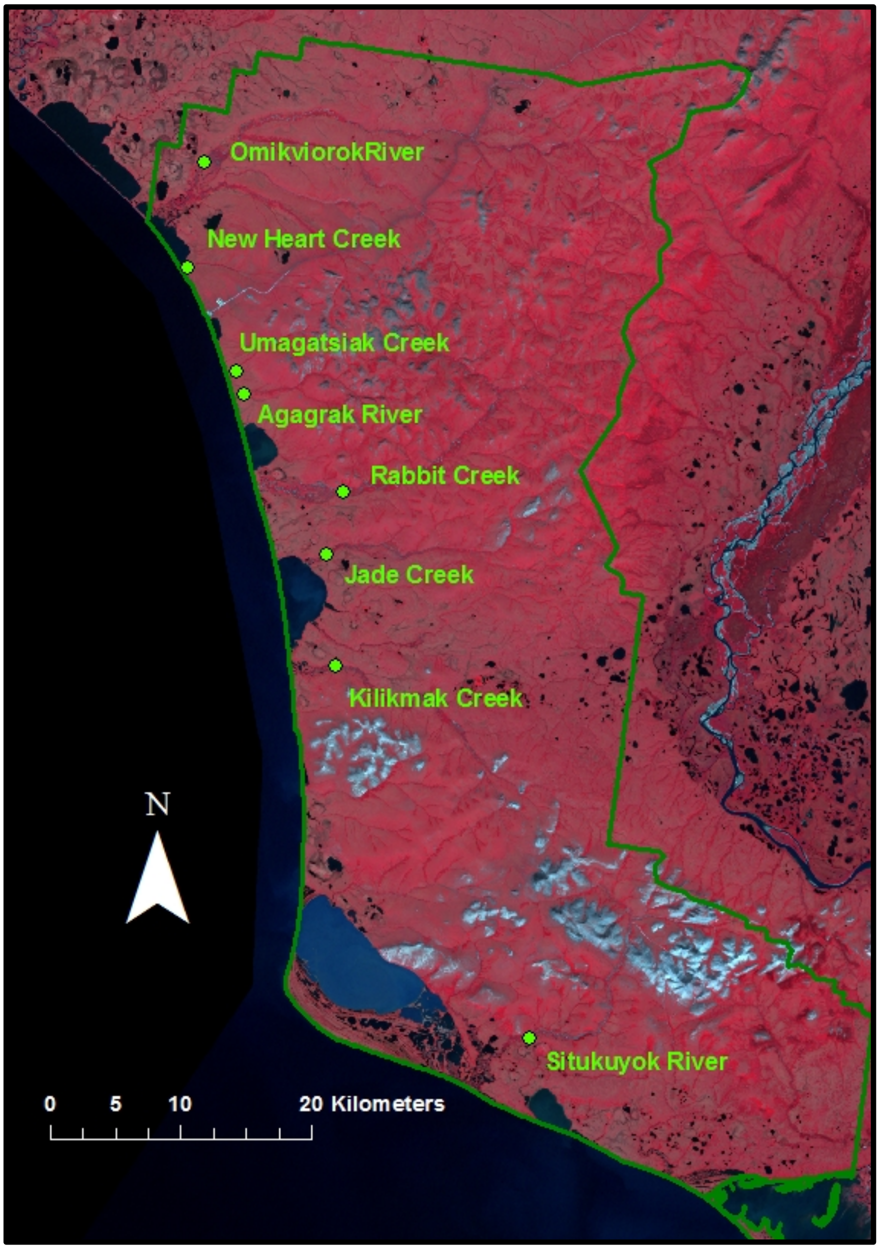

Figure A-12. Map of study sites sampled in July 2014 in Cape Krusenstern National Monument.

Agagrak River

The Agagrak River is a low- to mid-order stream draining a low-relief basin along the western coastal plain of CAKR. The stream channel at our study site was five to seven meters wide, and flow was low, with stage height approximately 0.5 m below recent high-water mark. Stream substrate was rocky, with many subangular flat rocks ranging in size from five to 20 cm in length. The stream appeared to be unproductive, with little algal or moss production on substrate. Short shrubs and dense moss carpets dominate riparian vegetation.

Figure A-13. Agagrak River study site, sampled on July 15, 2014.

Jade Creek

Jade Creek is a clearwater, mid-order stream with a deep, flat-bottom channel. River substrate was composed of small, sub-angular gravel. Flow was low, and stage height was approximately 0.5 m below recent high-water mark. Riparian vegetation dominated by various willow species. In the adjacent uplands, we observed polygonal ground and associated tundra vegetation.

Figure A-14. Jade Creek study site, sampled on July 15, 2014.

Kilikmak Creek

Kilikmak Creek is a mid-order stream flowing from east to west into the Bering Sea. At our study site, the stream channel was relatively deep (1.5 – 2.0 m) compared to other analogous streams in the region. Flow was relatively high, as evidenced by partially submerged terrestrial vegetation. We observed some fish rising in the deep channel. Vegetation in the riparian zone was a mixture of shrubs and tundra species.

Figure A-15. Killikmak Creek study site, sampled on July 15, 2015.

New Heart Creek

New Heart Creek is a small stream flowing from east to west toward the Bering Sea. At our study site, stream substrate was composed primarily of gravel and coarse sand, and no visible biofilm or algal production on substrate surface. Flow was low, with stage height approximately 0.75 m below the recent high-water mark. Riparian vegetation dominated by sedge meadow and coastal tundra species.

Figure A-16. New Heart Creek study site, sampled on July 15, 2014.

Omikviorok River

Omikviorok River is a small, braided stream with some abandoned sloughs within floodplain. At our study site, river substrate was composed of medium to large gravel, with significant algal production on substrate surface. Riparian vegetation was dominated by dense canopy of willows.

Rabbit Creek

Rabbit Creek is a mid-order stream flowing east to west into the Bering Sea. At our study site, stream substrate was dominated by sub-angular rocks of varying size. Flow was low, but there was evidence of recent high flows with frequent up-rooted shrubs on floodplain gravel bars. The riparian zone was dominated by short shrubs, but there were several tall shrubs on the gravel bars.

Figure A-17. Rabbit Creek study site, sampled on July 15, 2014.

Situkuyok River

Situkuyok River is a mid-order stream draining a high-relief tundra catchment. The stream originates near a pass between two mountains to the east, and then flows westward to the sea. During our site visit, flow was low. Stream substrate was composed of gravel and rocks, with algal biofilm covering ~80% of rocks. Riparian vegetation was composed primarily of a dense willow canopy.

Figure A-18 Situkuyok River study site, sampled on July 16, 2014.

Umagatsiak Creek

Uagatsiak Creek is a small, low-order stream flowing east to west into the Bering Sea. We sampled the creek approximately one mile upstream from the mouth. At our study site, stream substrate was composed of angular and sub-angular cobble and flat rocks. The stream channel was generally two-three meters wide, and flow was low. There was some evidence of recent deposition of sand and silt deposition on gravel bar. Riparian vegetation was dominated by sedges, and short and tall shrubs.

Figure A-19. Umagtsiak Creek study site, sampled on July 15, 2014.

Gates of the Arctic National Park

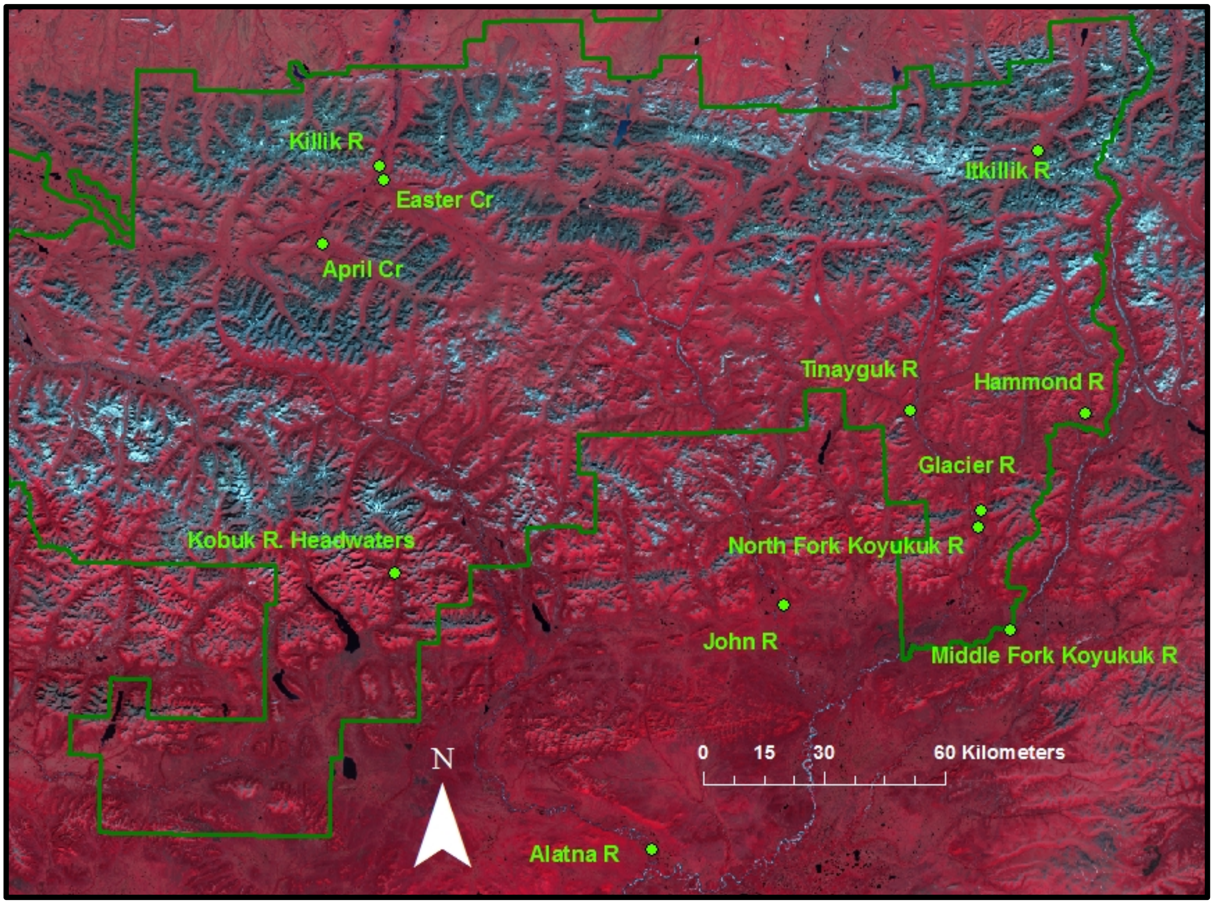

Figure A-20. Map of river study sites sampled in June and August 2014.

Alatna River

The Alatna River is a high-order river flowing from the northwest out of the Brooks Range, ultimately draining into the Koyukuk River. The sampling location was downriver from the southern park boundary near the confluence with the Koyukuk and the village of Allakaket. River substrate in this reach was composed of organic-rich very fine sand and small sub-angular gravel. The lower Alatna drains a low gradient catchment with many oxbows. Discharge and velocity were both low during sampling.

Figure A-21. The Alatna River study site, sampled on August 6, 2014.

April Creek

April Creek is a swift, mountain stream flowing from the east and draining into the upper Killik River. While flow velocity is fast during our site visit, discharge was relatively low, with stage height approximately 0.5 m below high-water mark. The stream channel was relatively deep, and the substrate dominated by large rocks. The river appears to be oligotrophic with little evidence of aquatic primary production. Alpine tundra vegetation dominates in the catchment, with dense shrub canopies lining the stream bank.

Figure A-22. April Creek study site, sampled on August 6, 2014.

Easter Creek

Easter Creek is a mid-order tributary of the Killik River, and the sampling location was 1-2 miles upstream of the confluence with the Killik. At our study site, the stream substrate was very rocky, with algal biofilm covering more than 80% of the riverbed. Flow was low, with stage height approximately 0.75 m below recent high-water mark. There were tall willows (2-3 m high) along the riparian shelf and gravel bars.

Figure A-23. Easter Creek study site, sampled on August 6, 2014.

Glacier River

Glacier River is a mid-order river draining from the east into the North Fork of the Koyukuk River. The river valley is U-shaped with a flat bottom. The river itself is wide and braided, but channel depth is relatively shallow (< 20 cm in most places). During our site visit, flow velocity was swift, but overall discharge appeared to be low. River substrate was composed of silt, very fine sand, and small gravel (possibly of glacial origin?). Willows dominated riparian vegetation and white spruce and aspen dominated uplands.

Figure A-24. Glacier River study site, sampled on August 5, 2014.

Hammond River

The Hammond is a mid-order river flowing from the northwest into the Middle Fork of the Koyukuk River. The study site is upstream of the canyon and numerous mining claims downstream of the GAAR boundary. At our study site, river substrate was rocky, with numerous rock faces exposed on the opposing bank from the sampling location. Flow was low, but velocity was swift with significant rapids in the canyon downstream from the study site. The river appeared to be oligotrophic in this reach, with no evidence of algal or invertebrate productivity. Vegetation was dominated by white spruce with shrub and moss understory.

Figure A-25. Hammond River study site, sampled on August 7, 2014.

Itkillik River

The Itkillik River study site was located in the headwaters of the Oolah Valley several miles downstream from Summit Lake. Here, the river drains a large, U-shaped glaciated valley. This section of the watershed is above tree line, with tundra vegetation in valley bottoms and exposed bedrock in uplands. During our site visit, flow was relatively low, with some evidence of higher flows on gravel bars. River water is clear. Approximately 50% of the rocky substrate was covered by an algal biofilm.

Figure A-26. The Itkillik River study site, sampled on August 8, 2014.

John River

The John is a large Arctic river flowing south of the Brooks Range through flats and ultimately into the Koyukuk River near Bettles. The sampling location is south of the GAAR park boundary and approximately 15 miles upriver of the confluence with Koyukuk. In this section, the river was low gradient yet flow as relatively swift. Water was clear and slightly green, reflecting possible carbonate lithology. The river substrate was composed of rocks and sand. In the section of the river, there was no evidence of algal or invertebrate production. Vegetation was dominated by white spruce and hardwoods.

Figure A-27. The John River study site, sampled on August 6, 2014.

Killik River

At our study site, the Killik River is a mid-orders stream flowing north out of the Brooks Range onto the North Slope and ultimately into the Colville River. Here, the river is draining a broad, U-shaped glaciated valley. The river substrate was a mixture and fine- and medium-sized sands with some small rocks. There was a bank exposure across from the study site composed of re-deposited glacial silt. Tundra vegetation dominated along the riverbanks with occasional shrubs (willow were 1-2 m height). Flow was relatively low, with stage height 1-2 m below top of the bank. The river appeared to be oligotrophic, with no evidence of algal or moss production on sediments.

Figure A-28. Killik River study site, sampled on August 6, 2014.

Kobuk River Headwaters

Our study site in the headwaters of the Kobuk River is characterized by clear, emerald waters flowing through a mountainous catchment. The river substrate was dominated by sandy substrate with variably sized sub-angular gravel. The river appears to be oligotrophic, with no visual evidence of algal or secondary productivity. Riparian vegetation was dominated by tall and short shrubs and white spruce in the uplands.

Figure A-29. Aerial view of the Kobuk River Headwaters study site, sampled on August 7, 2014.

Middle Fork of the Koyukuk River

The Middle Fork of the Koyukuk is a large river that flows from the north along the southeastern boundary of GAAR before joining the North Fork of the Koyukuk upstream of Bettles. Upstream of sampling location, the river parallels the Dalton Highway and pipeline, and flows through villages of Wiseman and Coldfoot. There are numerous active and inactive mining claims within the watershed. At our sampling location, the river was clear with an emerald color. Rocks and gravel dominated the river substrate. Flow was low, with the recent high-water mark approximately two meters above current stage height.

Figure A-30. Middle Fork of the Koyukuk River, sampled on August 7, 2014.

North Fork of the Koyukuk River

The North Fork of the Koyukuk River is a high-order river flowing south through the Brooks Range. Our study site was located downstream of the confluences with the Tinayguk and Glacier Rivers near the southern boundary of GAAR. We observed a large silty exposure on far side of river. The water was generally clear with a hint of green, possibly indicating carbonate lithology. Flow was relatively low, but there are class II/III rapids downstream of sampling location. The river substrate was rocky and sandy, with no evidence of algal biofilm or invertebrates. Tall alder (3-4 m) were observed on gravel bar terrace. White spruce dominated upland benches.

Figure A-31. North Fork of the Koyukuk River study site, sampled on 8/5/2014.

Tinayguk River

The Tinayguk River is a mid-order tributary of the North Fork of the Koyukuk River, and the sampling site is approximately one mile upstream of the confluence. The Tinayguk is a clearwater stream. River substrate was composed of cobble, rounded rocks, and sandy deposits. Flow was relatively low, with recent high-water mark 0.5 to 1.0 m above current stage height. Tall willows and black spruce dominated riparian vegetation. The river did not appear to be very productive, with no algal biofilm on substrate and no evidence of invertebrates under rocks.

Figure A-32. The Tinayguk River study site, sampled on 8/5/2014.

Kobuk Valley National Park

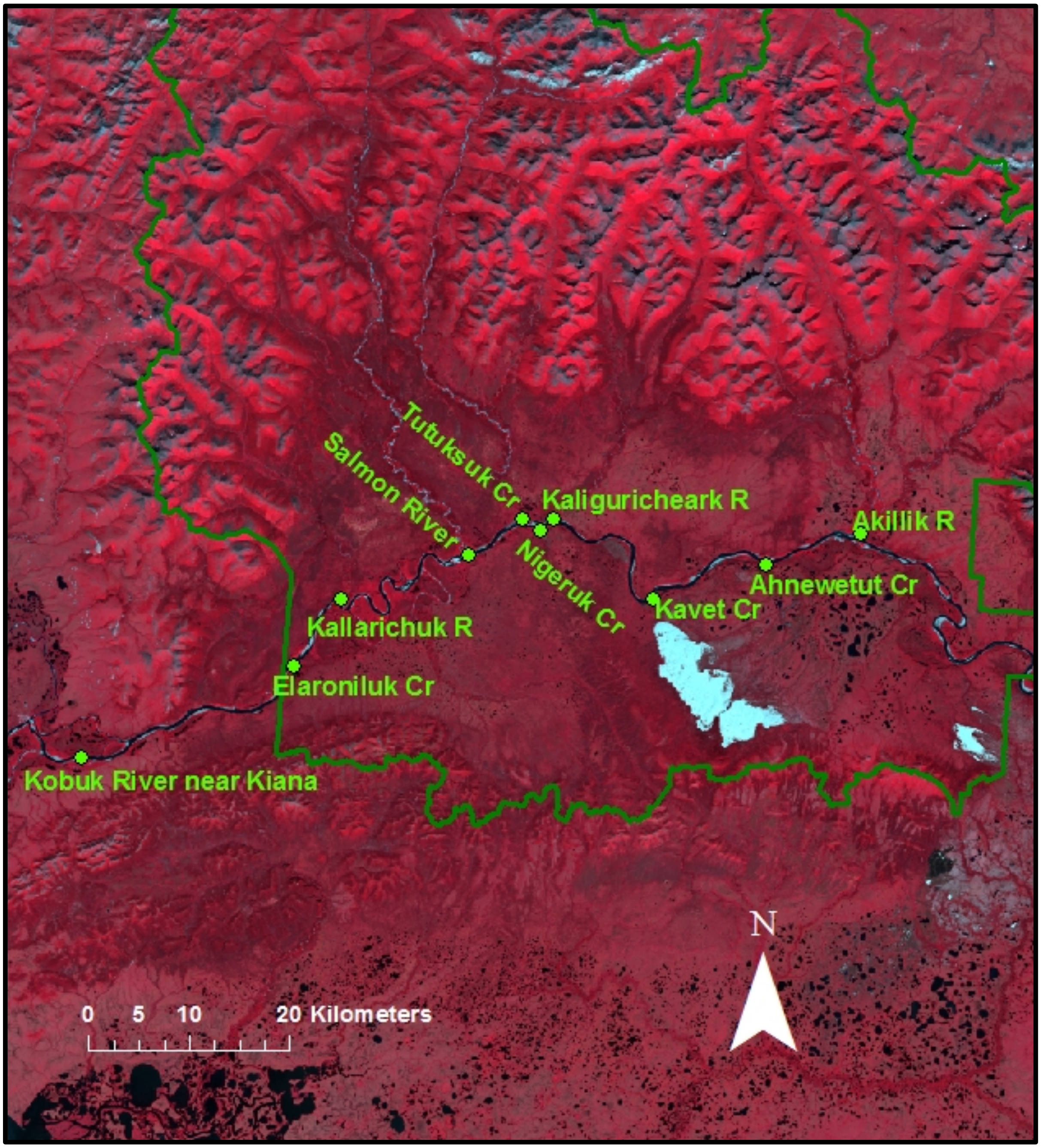

Figure A-33. Map of study sites in Kobuk Valley National Park.

Ahnewetut Creek

Ahnewetut Creek is a small tributary of the Kobuk River flowing south to north, draining a watershed that originates in the Great Kobuk Sand Dunes. The stream channel is 8-10 meters wide, with steep incised banks. At our study site, the river substrate was sand. Flow is low, with river stage height approximately one meter below recent high-water mark. Riparian vegetation dominated by willows, sedges, and various mosses. Small (~3 cm) juvenile fish were observed drift feeding in water column.

Figure A-34. Ahnewetut Creek study site, sampled on August 20, 2013.

Akillik River

The Akillik River is a major tributary of the Kobuk River, flowing from the north. River substrate at our study site was dominated by sand with some gravel. Flow was low (1-2 m below high-water mark) with a very shallow water table. Considerable driftwood had accumulated on sand bars. We observed a reddish biofilm along riverbanks and gravel bars (Fe-oxidizing bacteria?).

Figure A-35. The Akillik River study site, sampled on August 20, 2013.

Elaroniluk River

The Elaroniluk River is a low gradient, mid-order stream flowing from the southeast into the mainstem of the Kobuk River. River water at our study site was dark in color, reflecting high organic carbon content. River substrate was organic-rich sand colonized by algal biofilm. We observed some submerged aquatic macrophytes at study site. Riparian vegetation was composed of sedges and willows.

Figure A-36. Elaroniluk River study site, sampled on August 22, 2013.

Kaliguricheark River

The Kaliguricheark River is a high-order tributary of the Kobuk River and flows from north to south. At our study site, river substrate was primarily composed of gravel and cobble. The river appears to be highly productive, as reflected by the pervasive algal cover across stream bed. Flow was low during our site visit. We observed significant driftwood deposition on gravel bars and riverbanks. Riparian vegetation dominated by various willow species.

Figure A-36. Kaliguricheark River study site, sampled on August 21, 2013.

Kallarichuk River

The Kallarichuk River is a swift, meandering mid-order tributary of the Kobuk River. River substrate is a mixture of rocks and cobble and small (1-2 cm) gravel. Riparian vegetation at our study site was composed of tall shrubs and sedges.

Figure A-37. Kallarichuk River study site, sampled on August 22, 2014.

Kavet Creek

Kavet Creek is a low- to mid-order tributary of the Kobuk River that flows from south to north, draining the Great Kobuk Sand Dunes. At our study site, the river substrate was sand. Water was clear and likely alkaline. We observed aquatic mosses colonizing the streambed and riparian zone. Flow was low, as indicated by exposed sand shelf along river channel.

Figure A-38. Kavet Creek study site, sampled August 20, 2013.

Kobuk River at Kavet Creek

Figure A-39. The Kobuk River at Kavet Creek study site, sampled on August 8, 2013.

Kobuk River upstream of Kiana

Figure A-40. The Kobuk River near Kiana study site, sampled on August 23, 2013.

Nigeruk Creek

Nigeruk Creek is a low-order stream that flows south to north into the Kobuk River. During our site visit, we observed dark-red and brown organics in surface water. River substrate was fine sand mixed with variably sized gravel, and a thick algal and moss carpet was covering the streambed. Flow was relatively low, with river stage approximately 0.5 to 1-m below high-water mark. Dense willow canopies lined the stream channel with mixed shrub and white spruce in upland portions of the catchment.

Figure A-41. Nigeruk Creek study site, sampled on August 21, 2013.

Salmon River

The Salmon River is a high-order tributary flowing from north to south into the Kobuk River. At our study site, surface water was relatively clear and velocity was swift. River substrate was a mixture of sand and coble. The Salmon appears to be a productive system with significant algal production on stream bed. We observed lots of salmon and whitefish carcasses in the riparian zone. Our study site was near the confluence with the Kobuk, an area characterized by a broad, expansive gravel floodplain.

Figure A-42. Salmon River study site

Tutuksuk River

The Tutuksuk River is a high-order tributary flowing from the north to south into the Kobuk River. At our study site, river substrate is organic-rich mucky river sediments. We observed a strong fish smell in the area and lots of bear tracks. The channel is characterized by steep riverbanks. Flow as low, with river stage 2 to 3 meters below recent high-water mark. Riparian vegetation was composed of sedge lawn and willow canopy. We observed algal biofilm on >50% of the stream bed.

Figure A-43. Tutuksuk River study site, sampled on August 21, 2013.

Noatak National Preserve

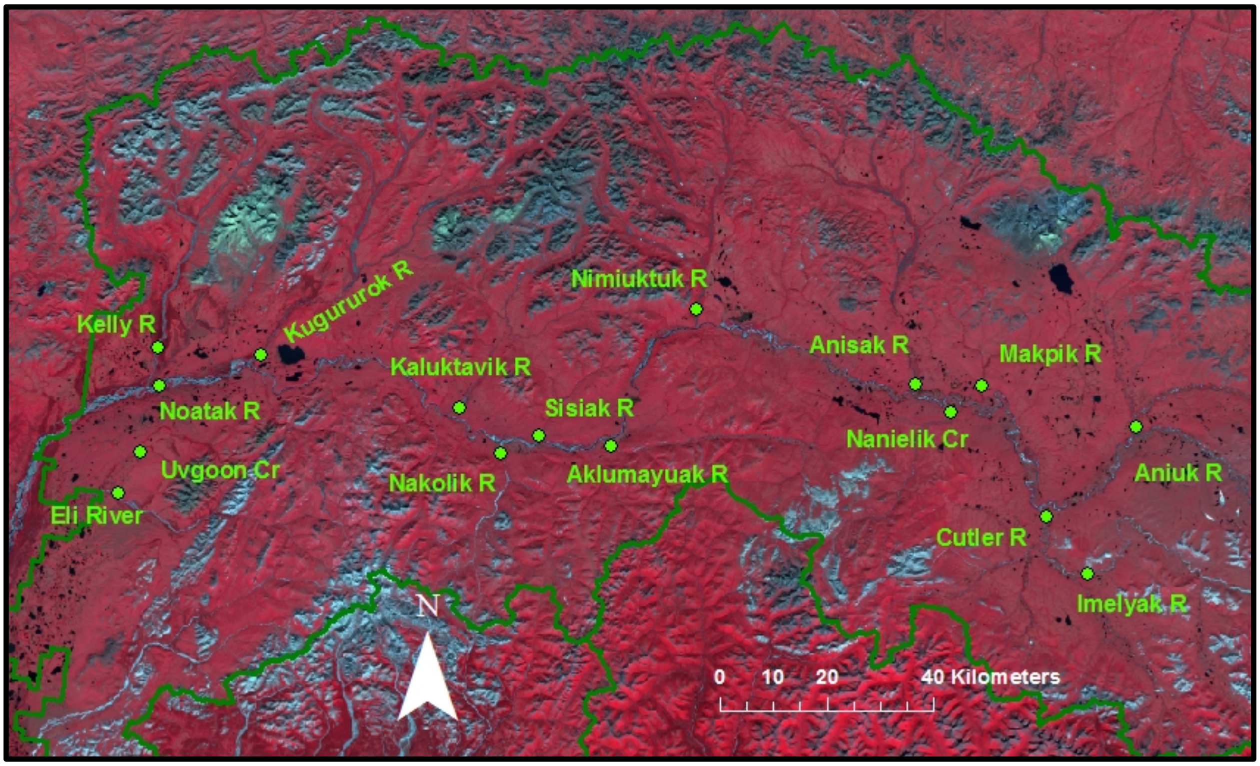

Figure A-44. Map of study sites in Noatak National Preserve.

Aklumayuak Creek

Aklumayuak Creek is a low-order creek with riffle-run-pool geomorphology. During our site visit, flow was low, with stage height approximately 1.5 m below high-water mark. Surface water was clear. River substrate was small (<5 cm) to medium-sized (up to 40 cm) rocks mixed with sand and some silt. River substrate has >80% algal biofilm cover. No signs of any invertebrates. Riparian vegetation includes short and tall willows, alder, equisetum, and fireweed.

Figure A-45. Aklumayuak Creek study site, sampled on June 28, 2013.

Anisak River

The Anisak River is a low-gradient, mid-order tributary of the Noatak River. During our site visit, flow was relatively low with moderate velocity through a rolling tundra watershed. River substrate was a mixture of rocks, cobble, and coarse sand. Gravel bars and riparian areas were sparsely vegetated by short shrubs and pockets of dense, tall willows.

Figure A-46. Anisak River study site, sampled on September 16, 2013.

Cutler River

The Cutler River is a swift-flowing tributary of the Noatak River lined by steep bluffs. The basin is characterized by a relative narrow active floodplain with willows and sedges in riparian zone and tussock tundra vegetation in upland parts of the watershed. At our study site, river substrate was a mixture of gravel and cobble.

Figure A-47. Cutler River study site, sampled on September 15, 2013.

Eli River

Eli River is a meandering, low-gradient river with frequent gravel and sand bars along river bends. At our study site, river substrate was variably sized sub-angular gravel, up to 30 cm in length. Flow is low but swift, with river stage 1 to 2 meters below recent high-water mark. Water was very clear, with slight blue-green coloration. Riparian gravel bars were sparsely vegetated with some willow. A cut bank revealed surficial sand and silt alluvial deposits overlying coarse sand and gravel material. The larger basin shows many abandoned and drying river channels and oxbow lakes. We did not observe any invertebrate larvae beneath channel rocks.

Figure A-48. Eli River study site, sampled on June 27, 2013.

Imelyak River

The Imelyak River is similar in size to Aniuk and Cutler Rivers. At our study site, river substrate was variably sized gravel, cobble, and coarse sand. Flow was low, but the current was swift current with river stage height 1 to 2 meters below the high-water mark. We observed light-green filamentous algae lining parts of streambed. Sparse willow and sedges lined rocky banks of the riparian zone. We also observed lots of caribou near the study site.

Figure A-49. Imelyak River study site, sampled on September 15, 2013.

Kaluktavik River

The Kaluktavik River is a mid- to high-order river draining a wide tundra basin with mountainous headwaters upriver from our sampling location. River substrate was rocky, although recent silt deposits were evident along gravel bar. The river was braided with many rocky gravel bars with some early successional willows colonizing. There were large aufeis fields both upstream and downstream of sampling site (very similar to Nimiuktuk River).

Figure A-50. Aerial view of the Kaluktavik River study site, sampled on June 28, 2013.

Kelly River

The Kelly River is a large, braided river with numerous channels separated by gravel bars and fine sand bars. Near our study site, rocks on gravel bars varied in size from <1 cm to greater than 15 cm. River water was very clear with green coloration, reflecting carbonate lithology. River substrate is similar to gravel bars, with variably sized gravel and rocks. We observed long filamentous algae/moss on a fraction of the riverbed. During our site visit, flow appeared to be declining along descending limb of the hydrograph following spring snowmelt.

Figure A-51. Kelly River study site, sampled on June 27, 2013.

Kugururok River

The Kugururok is a large tributary of the Noatak River, flowing through a broad valley with extensive active and inactive floodplains. At our study site, there were large gravel bars with coarse sand and variably sized gravel. The river was braided with two large channels at sampling site. Flow was low, with stage height approximately 1.5 meters below the high-water mark. Surface water was clear with green coloration, similar to Kelly and Eli Rivers. Dense willow and alder canopies lined the riverbank, with white in the uplands and some drunken spruce along river bank. We observed some algae, moss and invertebrates on river substrate. Driftwood cover <5% of the gravel bar.

Figure A-52. The Kugururok River study site, sampled on June 27, 2013.

Makpik River

Makpik River is a small tributary of the main-stem of the Noatak River. During our site visit, the current was swift current in deep channel, and river stage height was within 1-2 meters of the top of the bank. There were frequent gravel bars with a mixed substrate of rocks, cobble, and gravel. Riparian vegetation is composed of a dense willow canopy. We observed minimal algal biofilm on river sediments.

Figure A-53. Makpik River study site, sampled on September 16, 2013.

Nakolik River

The Nakolik River is a mid-order river flowing south to north towards its confluence with the main-stem of the Noatak River. The river is braided with gravel bars, consisting of gravel and rocks. During our site visit, water was very clear with aqua coloration. Flow was low, with river stage height 1 to 2 meters below high-water mark. We did not observe any invertebrates and relatively little algal biofilm. Riparian vegetation is composed of willows and alders.

Figure A-54. Nakolik River study site, sampled on June 28, 2013.

Nanielik Creek

Nanielik Creek is a small tributary flowing from south to north into the main stem of the Noatak River. At our study site, river substrate was a mixture of gravel, cobble, and coarse sand. Flow was low, with moderate velocity along riverbanks. Algal biofilm was present on most rocks and cobble along stream bed.

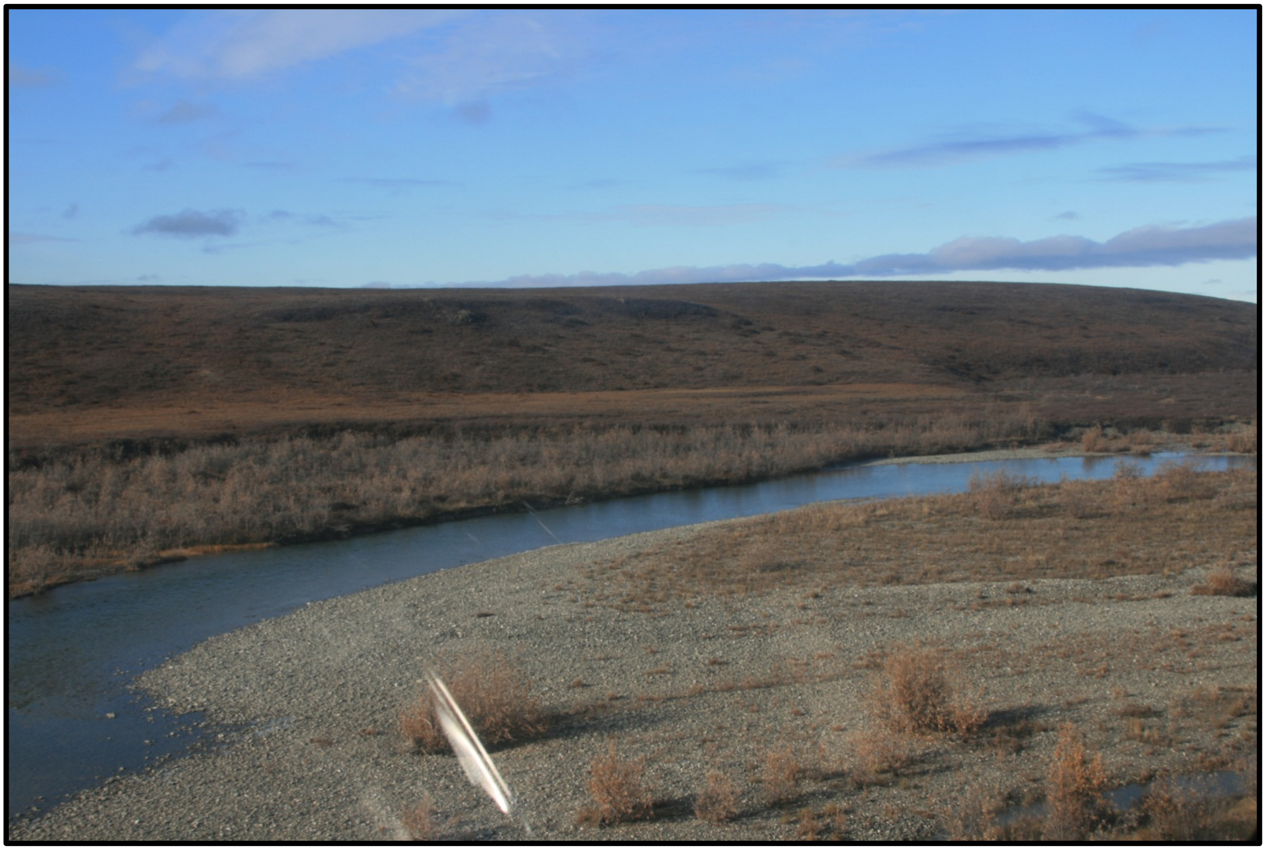

Figure A-55. Nanielik Creek study site, sampled on September 16, 2013.

Nimiuktuk River

The Nimiuktuk River is a high-order mountain river. Here, river flow appeared to be generated by a significant regional groundwater source, as evidenced by the large aufeis field downstream of the sampling site. The river was braided with frequent gravel and silt bars and side channels. Flow was low, with river stage height approximately 1 meter below recent high-water mark. Surface water was clear. Vegetation cover was variable on gravel bars, but dominated by willows. Alder was also present along river banks and early successional silt deposits. River substrate was primarily gravel and cobble (2-25 cm in size). Thin algal biofilm was observed on 40-50% of rock surfaces. We did not observe any invertebrate larvae beneath river substrate.

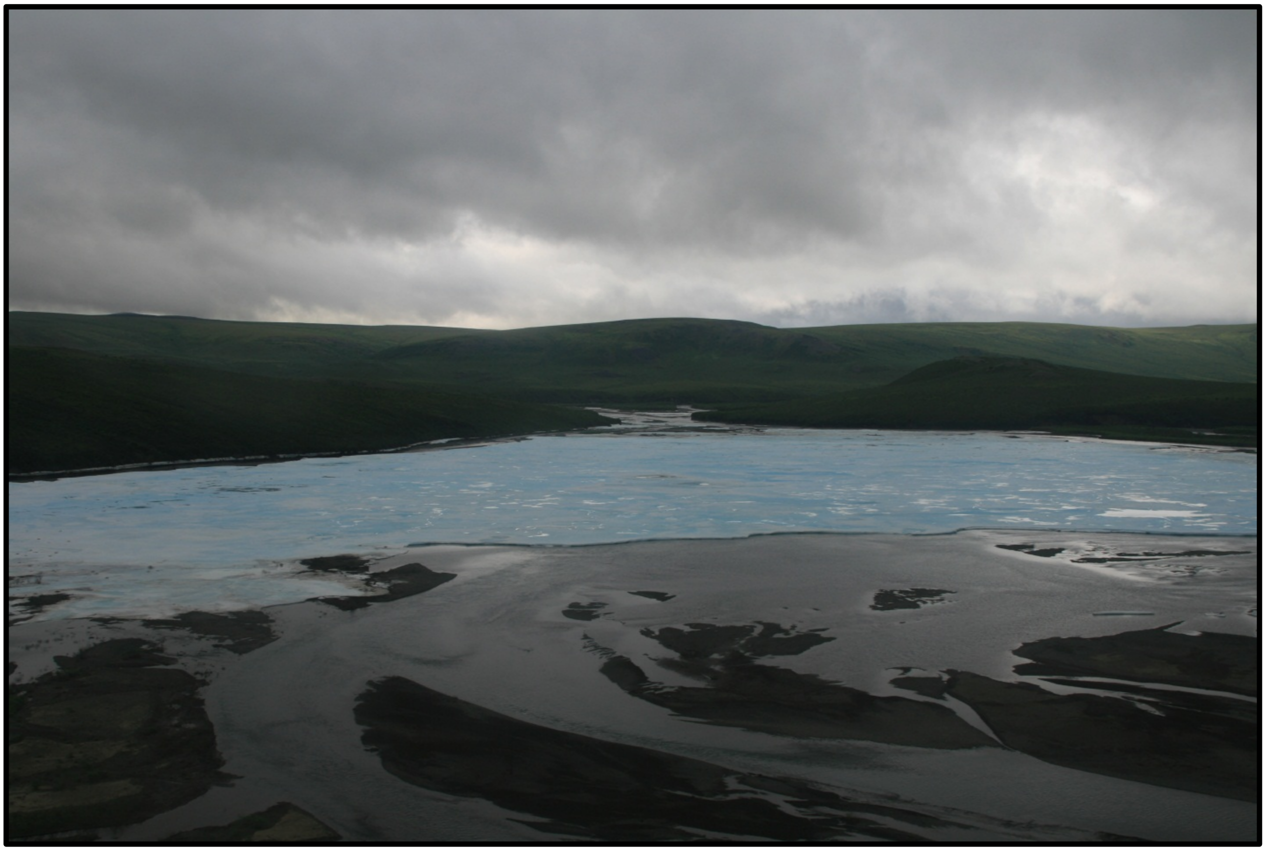

Figure A-56. Nimiuktuk River study site, sampled on June 28, 2013.

Noatak River

We sampled the Noatak River just downriver from Kelly Ranger Station. The Noatak is a large arctic river at this point, at least 300-m wide. Surface water was clear water with aqua coloration in deeper channels. Willows dominated riparian vegetation with white spruce in the uplands.

Figure A-57. Noatak River study site near the confluence with Kelly River, sampled on June 27, 2013.

Sisiak Creek

Sisiak Creek is a ;ow-order stream draining a watershed near the Sisiak weather station. The stream is characterized by a riffle-run-pool geomorphology, with a slightly higher gradient than Aklumayuak Creek. At our study site, river substrate was composed of gravel, rocks, and coarse sand. River rocks have thick algal biofilm and filamentous algae. Surface water was relatively clear, but algal production indicates high nutrient concentrations. Flow was swift but discharge was low. However, we did observe evidence of recent flooding on gravel bars with re-transported willows. Riparian vegetation was a mixture of short and tall willows and alders.

Figure A-58. Sisiak Creek study site, sampled on June 28, 2013.

Uvgoon Creek

Uvgoon Creek is a low gradient and meandering stream. The study site was downstream from a recent tundra fire. Riparian vegetation was composed of white spruce, dense alder and willow shrubs. Upland vegetation was typical of tussock tundra ecosystems. Stream geomorphic setting included gentle riffles and runs with silty gravel bars along bends. Surface water was relatively clear with slight coloration, indicating the presence of aromatic DOC. Flow was low on descending limb of hydrograph following snowmelt, with river stage 0.5 meters below recent high-water mark. River substrate was rocky and gravelly, with thin algal biofilm present on some rocks.

Figure A-59. Uvgoon Creek study site, sampled on June 27, 2013.

NPS 953/ 128986, June 2015

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